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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

FREE-SPINNING-TUNNEL TESTS OF A $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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FREE-SPINNING-TUNNEL TESTS OF A $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE

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SUMMARY

A spin-tunnel investigation of a $\frac{1}{26}$-scale model of the Douglas XTB2D-1 airplane has been conducted in the Langley 20-foot free-spinning tunnel. The effects of control settings and movements upon the erect- and inverted-spin and recovery characteristics of the model were determined for various loading conditions. Tests were also performed to determine the effects of various tail modifications. The investigation included emergency spin-recovery parachute tests as well as crew-escape and rudder- and elevator-force tests. All tests were performed at an equivalent spin altitude of 20,000 feet.

The recovery characteristics of the model in its original design were found to be unsatisfactory. Installation of a large ventral fin, installation of tip fins on the horizontal tail, or installation of a small ventral fin in combination with antispar fillets and a spanwise extension of the horizontal-tail surfaces satisfactorily improved the recovery characteristics of the model. Analysis indicates that moving the horizontal tail upward and forward sufficiently will also lead to satisfactory recoveries. A 19.5-foot tail parachute with a drag coefficient of 0.60 or a 7.6-foot wing-tip parachute opened on the outboard wing tip with a drag coefficient of 0.59 was found to be satisfactory as an emergency spin-recovery device for demonstrations. It was indicated that in an emergency the crew should leave the airplane in a spin from the outboard side or from below the fuselage rearward of the wing. The rudder and elevator control forces measured were found to be

[redacted] [redacted]

beyond the capabilities of the pilot. Some suitable booster system will be necessary on the airplane to obtain the full control movements for recovery.

INTRODUCTION

In accordance with the request of the Bureau of Aeronautics, Navy Department, model tests were performed in the Langley 20-foot free-spinning tunnel to determine the spin and recovery characteristics of the Douglas XTB2D-1 airplane. The XTB2D-1 is a low-wing, single-engine, three-place airplane with contra-rotating propellers. In order to expedite tests, two $\frac{1}{26}$-scale models of the airplane were used.

The spin and recovery characteristics were determined for the normal loading (two external torpedos) and for several other possible loadings, including asymmetrical loadings. Several modifications were tested to improve the spin and recovery characteristics of the model. The effects of wing-tip and tail parachutes as devices for emergency recovery from demonstration spins were investigated. In addition, tests were performed to determine the best method for the crew to leave the airplane if in an uncontrolled spin, and to determine the control forces required to move the controls for recovery from a spin.

SYMBOLS

b	wing span, feet
m	mass of airplane, slugs
S	wing area, square feet
c	wing chord, feet
$\bar{c}$	mean aerodynamic chord, feet
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord

$y/\bar{c}$	ratio of distance between center of gravity and plane of symmetry to mean aerodynamic chord (positive when center of gravity is to right of plane of symmetry)
$z/\bar{c}$	ratio of distance between center of gravity and thrust line to mean aerodynamic chord (positive when center of gravity is below thrust line)
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-feet^2
$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter
ρ	air density, slug per cubic foot
$\mu = \frac{m}{\rho Sb}$	relative density of airplane
α	angle between thrust line and vertical (approximately equal to absolute value of angle of attack at plane of symmetry), degrees
ϕ	angle between span axis and horizontal, degrees
V	full-scale true rate of descent, feet per second
Ω	full-scale angular velocity about spin axis, revolutions per second
σ	helix angle, angle between flight path and vertical, degrees (For this model, the average absolute value of the helix angle was approximately 3°.)
β	approximate angle of sideslip at center of gravity, degrees (Sideslip is inward when inner wing is down by an amount greater than the helix angle.)

APPARATUS AND METHODS

Model

The $\frac{1}{26}$-scale models of the Douglas XTB2D-1 airplane were furnished by the Bureau of Aeronautics, Navy Department, and were checked dimensionally and prepared for testing by Langley. Dimensional characteristics of the airplane are given in table I. A three-view drawing of the models in the normal loading is shown in figure 1. Figure 2 is a photograph of one of the models in the normal loading. Sketches of the modifications tested are shown in figures 3 and 4.

As previously indicated, two models were built to expedite the tests. Because the actual dihedral of the airplane had not been decided upon but was to be either 8° or 10°, one model was constructed with 8° and the other with 10° dihedral.

The models were ballasted with lead weights to obtain dynamic similarity to the airplane at an altitude of 20,000 feet ($\rho = 0.001267$ slug per cubic foot). The weight, moments of inertia, and center-of-gravity location of the airplane were obtained from data furnished by the Douglas Aircraft Company. A remote-control mechanism was installed in the model to actuate the controls or to open the parachute for recovery tests, and also to release the dummy crewman for crew-escape tests. Sufficient hinge moment was applied to the control surfaces during the regular test program to move them fully and rapidly to the desired positions.

The model parachutes used were of the circular flat type made of silk. Drag coefficients, measured at the time of tests, based on the surface area of the canopy when spread out flat, are listed in table II.

The $\frac{1}{26}$-scale dummy used for the crew-escape tests was constructed at Langley and was scaled down both in dimensions and weight to represent a crew member and parachute (220 pounds) at an altitude of 20,000 feet.

The propellers were not simulated on the model because the results of previous tests (data unpublished) have indicated little effect of a windmilling propeller on the spin and recovery characteristics of models of conventional airplanes.

Fixed elevator slats, simulating those of the airplane, were installed on the model as shown in figure 4.

Wind Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is generally similar to that described in reference 1 for the 15-foot free-spinning tunnel except that the model launching technique has been changed. With the controls set in the desired position the model is launched by hand with rotation into the vertically rising air stream. After a number of turns in the established spin, recovery is attempted by moving one or more controls by means of the remote-control mechanism. After recovery, the model dives into the safety net. The data presented were determined by methods described in reference 1 and have been converted to corresponding full-scale values. A photograph of the model spinning in the tunnel is shown in figure 5.

In accordance with standard spin-tunnel procedure, tests were performed to determine the spin and recovery characteristics of the model for the normal spinning control configuration (elevator full up, ailerons neutral, and rudder full with the spin) and for various other aileron-elevator combinations including neutral and maximum deflections of the surfaces for various model loadings and configurations. Where spins were obtained, recovery was attempted either by rapid full reversal of the rudder or by rapid full reversal of both rudder and elevator. If the model recovered without control movement when launched in a spinning attitude with the controls set for the spin, the condition was recorded as "no spin."

Tests were also performed to evaluate the possible adverse effects on recovery of small deviations from the normal control configuration for spinning. For these tests, the ailerons were set one third of their full deflection in the direction conducive to slower recoveries, with the spin for the XTB2D-1 model (stick right in a right spin) and the elevator was set at two-thirds full-up or full-up deflection. Recovery was attempted by either rapidly reversing the rudder from full-with to two-thirds against the spin or by movement of the rudder to two-thirds against the spin in conjunction with moving the elevator to one-third down. This particular control configuration and movement is referred to as the "criterion spin."

The turns for recovery were measured from the time the controls were moved to the time the spin rotation ceased. The criterion for a satisfactory recovery from a spin for a spin-tunnel model has been adopted as two turns or less based primarily on the probable loss of altitude of a corresponding airplane during recovery and the subsequent dive. As a result of spin-tunnel experience, the recovery characteristics of a model are considered satisfactory if recovery requires no more than $2\frac{1}{4}$ turns from the criterion spin.

For the spins which had a rate of descent in excess of that which can be readily attained in the tunnel, the rate of descent was recorded as greater than the velocity at the time the model hit the safety net, as for example, >300 feet per second. For these tests, recovery was usually attempted before the model reached its final steeper spin attitude and while the model was still descending in the tunnel. Such results are considered conservative. For recovery attempts in which the model struck the safety net while it was still in a spin, the recovery was recorded as greater than the number of turns observed from the time the controls were moved to the time the model struck the safety net, as >3. A >3-turn recovery does not necessarily indicate an improvement over a >7-turn recovery.

The testing technique for determining the optimum size of, and the towline length for, spin-recovery parachutes is described in detail in reference 2. In brief, the model in the original configuration was launched with rotation into the tunnel with the rudder set full with the spin. Wing-tip parachutes were attached to the outer wing tip (left wing tip in a right spin). When the parachute was attached to the wing tip, the towline length was so adjusted that the parachute would just clear the stabilizer when fully extended. In every case the folded parachute was placed on the fuselage or on the wing in such a position that it did not influence the steady spin before the parachute was opened. (It is recommended that for the full-scale wing-tip installations, the parachute be packed within the wing structure. A positive means of ejection should be provided for any parachute installation.) For the current tests, the controls were not moved during recovery so recovery was due entirely to the effect of opening the parachute.

For the tests to determine from which side of the spinning airplane it would be safer for the crew to escape in an emergency, the dummy was released from the inboard side and from the outboard side of the fuselage at the cockpit and from the bottom of the tub-like structure located below the fuselage near the trailing edge of the wing, denoted as the "bomber's tub." These tests were performed for both typical flat and typical steep spins.

PRECISION

The spin results presented herein are believed to be the true values given by the models within the following limits:

α, percent	±1
ϕ, percent	±1
Ω, percent	±3
V, percent	±5
Turns for recovery	±1/4 from motion picture records ±1/2 from visual observation

The preceding limits may have been exceeded for certain spins in which it was difficult to control the model in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

Comparison between model and airplane spin results (references 1 and 3) indicates that spin-tunnel results are not always in complete agreement with airplane spin results. In general, the models spun at a somewhat smaller angle of attack, at a somewhat higher rate of descent, and at from 5° to 10° more outward sideslip than did the corresponding airplanes. The comparison made in reference 3 for 20 airplanes showed that 16 of the models predicted satisfactorily the corresponding airplane recovery characteristics and that 2 of them overestimated and that 2 of then underestimated the corresponding number of turns for recovery.

Little can be stated about the precision of the crew-escape tests as little comparable full-scale data are available. It is considered that when the dummy crewman is observed to clear all parts of the model by a large margin after being released, the crewman of the corresponding airplane can escape from an uncontrollable spin of the airplane.

Because of the impracticability of ballasting the model exactly and because of inadvertent damage to the models during the spin tests, the measured weight and mass distribution of the models varied from the true scaled-down values. The following table shows the range of weight and mass distribution variations measured for both models:

Weight, percent		0 to 3 high
Center-of-gravity location, percent $\bar{c}$		5 forward to 3 forward
Moments of inertia	I_X, percent	2 low to 13 high
	I_Y, percent	5 low to 1 high
	I_Z, percent	3 high to 13 high

The accuracy of measuring the weight and mass distribution of the models are believed to be within the following limits:

Weight, percent	± 1
Center-of-gravity location, percent $\bar{c}$	± 1
Moments of inertia, percent	± 5

The controls were set with an accuracy of ± 1°.

TEST CONDITIONS

Tests were performed for the model conditions listed on table III. The mass characteristics and inertia parameters for loadings possible on the airplane and tested on the models are listed on tables IV and V, respectively. The inertia parameters for the loadings of the XTB2D-1 airplane and for the loadings tested on the model are plotted in figure 6. As discussed in reference 4, figure 6 can be used as an aid in predicting the relative effectiveness of the controls on the spin and recovery characteristics of the model.

Tail-damping power factors were computed by the method described in reference 5 and, for the original tail configuration, the factor was 197×10^{-6}. Tail-damping power factors for all configurations tested are listed on table VI.

The normal maximum control deflections used in the current tests were:

Rudder, degrees	25 left, 25 right
Elevator, degrees	29 up, 21 down
Ailerons, degrees	14.3 up, 14 down

The intermediate control deflections used were:

Rudder two-thirds deflected, degrees	$16\frac{2}{3}$
Elevator two-thirds up, degrees	$19\frac{1}{3}$
Elevator one-third down, degrees	7
Ailerons one-third deflected, degrees	4.8 up, 4.7 down

For all the tests, the landing flaps and dive flaps were neutral, the landing gear was retracted, and the cockpit was closed.

RESULTS AND DISCUSSION

The results of the tests are presented in tables II and VII and on charts 1 to 8. For both models, right spins were generally steep with recovery satisfactory if both the rudder and elevator were reversed, while left spins were flat with unsatisfactory recoveries, regardless of control movement. Tests were performed to determine the cause of the asymmetrical results obtained to the right and left and the results indicated that the asymmetry was not caused by the radar unit mounted at the right wing dihedral break. It appears that the difference in results was probably due to slight, inadvertent, asymmetric model construction, which although within construction tolerances, nevertheless affected the results of the current design appreciably. Both models were affected similarly. It thus appears that small variations in the airplane construction, within production tolerances, may also result in a range of recovery characteristics, with a definite possibility of unsatisfactory recoveries. Accordingly, modifications were tested on the model for left spins to determine an effective modification which would eliminate the possibility that the airplane might enter an uncontrollable spin.

The initial results obtained with the two models indicated that the effect of the small wing dihedral difference contemplated (8° and 10°) was not significant. Tests thereafter were made on either model as was expeditious to the test program. The discussion, presented herein, is treated in terms of one model.

Normal Loading

Erect spins.- The test results obtained with the model spinning erect in the normal loading are shown in chart 1. For left spins, when the ailerons were neutral or when the ailerons were with the spin (left aileron up in a left spin) the model spun steadily in a fairly flat attitude for all elevator positions. When the ailerons were against the spin, the spins were steep and oscillatory in pitch. The oscillation was periodic, varying from flat to steep in approximately one turn. With the elevators down and the ailerons against the spin the model would not spin. Recoveries from left spins could not be obtained by rudder reversal alone from the spin at normal control configuration for spinning or from the criterion spin.

Movement of the elevator down simultaneous with rudder reversal resulted in recoveries which, however, were not satisfactory. For right spins, all the spins were steeper than were those at corresponding control configurations to the left. The pattern of control effectiveness (elevator and aileron effectiveness) was, however, the same as that for left spins. Recoveries obtained from right spins by rudder reversal alone were marginal but those obtained by simultaneous reversal of both the rudder and elevator were rapid. These results indicate the importance of downward movement of the elevator for recovery for this particular design and loading. These results are in agreement with the effects of mass distribution as indicated in reference 4.

Inverted spins.- Chart 2 gives the test results obtained with the model spinning inverted. The order used for presenting the data for inverted spins is different from that used for erect spins. For inverted spins, "controls crossed" (left rudder pedal forward and stick to pilot's right) for the established spin is presented to the right of the chart and stick-back is presented at the bottom of the chart. When the controls are crossed in the established inverted spin, the ailerons aid the rolling motion; when the controls are together the ailerons oppose the rolling motion. The angle of wing tilt on the chart is given as up or down relative to the ground.

The model would spin only with the controls crossed and recoveries from all spins obtained were satisfactory by rapid full reversal of the rudder.

Rearward Center of Gravity

The results of tests performed to determine the effect of moving the center of gravity rearward 10 percent of the mean aerodynamic chord are presented in chart 3. Only a rearward center-of-gravity movement was investigated because experience has shown that this direction is the one most adverse to spin and recovery characteristics. In general, the steady-spin and the recovery characteristics of the model for this center-of-gravity position were similar to those for the normal center-of-gravity position. (See chart 1.) This rearward movement of the center of gravity exceeds that possible on the airplane as indicated by the Douglas Company and it thus appears that movement of the center of gravity as far rearward as possible on the airplane will have negligible effect.

Overload Torpedo Condition

Test results obtained with the model simulating the overload torpedo condition (four torpedos installed on the wing racks and additional fuel carried in the internal wing tanks) are presented in chart 4. For the spins tested the model spun at angles of attack similar to those of corresponding spins of the model in the normal loading and recoveries were also generally similar.

Asymmetrical Loadings

Chart 5 shows the results of tests with the model loaded asymmetrically, exclusive of the radar unit. For these tests a torpedo was mounted first on the inner rack of the two racks on the left wing and then on the right wing for left spins. Spin recoveries became more difficult to obtain than those for the normal loading (chart 1) when the torpedo was on the left wing in a left spin whereas with the torpedo on the right wing in a left spin recoveries were greatly improved.

Tail Modifications

The results of tests of modifications to the tail of model in the normal loading are presented in table VII and charts 6 and 7. In order to expedite the test program, several of the modifications and combinations of some of the modifications that did not appear very promising after initial tests were not tested completely and are not discussed separately. For some of these modifications, oscillatory spins were obtained and although recoveries from the steep phase of the oscillation were satisfactory, recoveries from the flat phase were unsatisfactory. The results of these brief tests are presented in table VII.

Ventral fin 2.- The test results obtained from left spins with ventral fin 2 are given in chart 6. The steady spins were steeper than corresponding spins with the normal tail configuration. Recoveries by simultaneous rudder and elevator reversal were considered satisfactory from any phase of the spin oscillation obtained. A ventral fin of this size of the airplane, however, would interfere with the arresting gear hook and ground clearance and therefore is probably not practicable for installation on the airplane.

Revised horizontal-tail position.- Based on the results of tests of the model with ventral fin 2 installed and on spin-tunnel experience it is estimated that movement of the horizontal tail upward and forward an adequate amount will result in satisfactory recovery characteristics for the subject airplane. Raising the horizontal tail 39 inches and moving it forward 26 inches, a position in which the leading edge of the stabilizer approximately coincides with that of the vertical fin, will result in a tail damping power factor similar to that of the airplane with ventral fin 2 installed and would probably lead to similar results.

Tip fins.- The results of tests with tip fins installed on the ends of the horizontal tail are presented in chart 7. These fins were installed to supply more fixed fin area for damping the spinning rotation. The spins obtained were steeper than corresponding normal tail configuration spins and recoveries were considered satisfactory.

Ventral fin 1, antispin fillets 2, and horizontal-tail spanwise extension.- Several modifications which individually had not proven sufficiently effective although they had improved recoveries somewhat (table VII), were tested in combination. The results presented on chart 8 show the effect of a small ventral fin in combination with antispin fillets and a spanwise extension of the horizontal tail. The spins obtained with this combination of modifications were steeper and more oscillatory in pitch than those for corresponding control deflections with the original tail. Satisfactory recoveries by simultaneous reversal of both the rudder and elevator were obtained from all phases of the spin oscillation with this configuration of the model in the normal loading.

Tests results with the center of gravity moved rearward 10 percent of the mean aerodynamic chord, also presented on chart 8, also indicated satisfactory recovery characteristics for this combination of modifications.

Spin-Recovery Parachute Tests

The test results obtained for erect spins with spin-recovery parachutes are presented in table II. The results show that a tail parachute 19.5 feet in diameter (full scale) with a drag coefficient of 0.60 will be necessary to insure satisfactory recovery by parachute action alone. The results also indicate that a towline approximately 36 feet long will be adequate. Satisfactory recovery was also obtained by opening a 7.6-foot diameter wing-tip parachute, having a drag coefficient of 0.59, with an 18-foot towline on the outboard wing tip (right wing tip in a left spin).

Crew-Escape Tests

The results of the crew-escape tests were interpreted to indicate that the crew members could safely leave the spinning airplane in an emergency from the outboard side (right side in a left spin) of the airplane or from the bottom of the "bomber's tub." If any crew member has a choice of possible exits it would probably be safest to leave through the "bomber's tub."

Landing and Diving Conditions

The landing and diving conditions were not tested on the model inasmuch as current Navy specifications do not require this type of airplane to pass spin demonstrations in the landing or diving conditions.

An analysis of full-scale and model tests to determine the effect of flaps and landing gear, in the event that the airplane is inadvertently spun in these conditions, indicates that although the XTB2D-1 airplane will probably recover satisfactorily from an incipient spin in the landing or diving conditions, recoveries from fully developed spins will probably be unsatisfactory. It is recommended therefore that the flaps be neutralized and recovery attempted immediately upon inadvertently entering a spin in the landing or diving conditions in order to insure that transition from the incipient to the fully developed spin does not take place.

Control Forces

The discussion of the results so far has been based on control effectiveness alone without regard to the forces required to move the controls. For all tests, sufficient force was applied to the controls to move them fully and rapidly. Sufficient force must be applied to the airplane controls to move them in a similar manner in order for the model and airplane results to be comparable.

A few tests were performed with the model in the normal loading in which the forces applied to the rudder and elevator, in order to effect a satisfactory recovery, were measured. The results indicated that the full-scale pedal and stick forces would both be beyond the capabilities of the pilot, each being of the order of magnitude of 1000 pounds. It is therefore recommended that some suitable booster be used on the airplane. Because of lack of detail in the rudder and elevator balances of the model, of inertia mass-balance effects, and of scale effect, these results are only qualitative indications of the actual forces that may be experienced.

Recommended Recovery Technique

Based on the results obtained with the model, the following recommendations are made for all loadings and conditions of the airplane:

With the airplane in the original configuration, intentional spins should be avoided and recovery should be attempted immediately upon entering an inadvertent spin.

For erect spins the rudder should be reversed briskly from full with to full against the spin, followed immediately by movement of the stick full forward, maintaining it laterally neutral; care should be exercised to avoid excessive rates of acceleration in the ensuing recovery dive. If flaps are extended they should be neutralized. When only one torpedo is installed on the wing racks, the torpedo should be jettisoned and recovery attempted immediately.

For inverted spins the rudder should be reversed briskly and the stick moved to neutral (laterally and longitudinally).

CONCLUSIONS AND RECOMMENDATIONS

Based on results of spin tests of $\frac{1}{26}$-scale models of the Douglas XBT2D-1 airplane, the following conclusions and recommendations regarding spin and recovery characteristics of the airplane at a test altitude of 20,000 feet are made:

1. Because of the critical nature of the design with regards to spin recovery, recoveries from fully developed spins will probably be unsatisfactory. In the original design, intentional spins should be prohibited and recovery should be attempted immediately upon entering an inadvertent spin.

2. For recovery the rudder should be reversed fully and rapidly followed immediately by movement of the stick full forward.

3. Movement of the horizontal tail upward and forward; installation of tip fins on the horizontal tail; or combination of a small ventral fin, antispan fillets, and a spanwise extension of the horizontal tail will result in satisfactory recovery characteristics.

4. Satisfactory recoveries will be obtained from inverted spins by reversing the rudder and neutralizing the stick.

5. A 19.5-foot tail parachute with a drag coefficient of 0.60 or a 7.6-foot wing tip parachute with a drag coefficient of 0.59 will effect satisfactory recoveries from demonstration spins for any of the tail configurations discussed herein.

6. If necessary to abandon the airplane in a spin, the crew should leave from the outboard side of the airplane or from below the fuselage at the "bomber's tub."

7. The control forces encountered in a spin will probably be beyond the capabilities of the pilot. A suitable booster for decreasing the control forces will be necessary to permit reversal of controls for recovery.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF THE

DOUGLAS XTB2D-1 AIRPLANE

Length over all, ft	46
Co-axial-propeller diameters, ft	14.75 front 14.18 rear
Propellers, number of blades each	4
Normal weight, lb	26,343
Normal center-of-gravity location, percent $\bar{c}$	25
Wing:	
Dihedral, deg	
Center sections	0
Outer panels	10 or 8
Wing span, ft . . . . . . 70.2 (10° dihedral), 70.3 (8° dihedral)	
Area, sq ft	608.27
Section root (Douglas designation)	E.S. 8H4518
Section tip (Douglas designation)	E.S. 8H4516
Root chord incidence, deg	2
Tip chord incidence, deg	0
Aspect ratio	8.1
Mean aerodynamic chord, in.	108
Flap, hinge line to trailing edge, percent chord	17.5
Ailerons:	
Hinge line to trailing edge, percent chord	17.5
Span, percent of b/2	44.5
Horizontal-tail surfaces:	
Total area, sq ft	148.2
Span, ft	25.8
Elevator area, sq ft	56.1
Distance from normal center of gravity to elevator hinge line, ft	27.5
Vertical-tail surfaces:	
Total area, sq ft	82.2
Total rudder area, sq ft	35.6
Distance from normal center of gravity to rudder hinge line, ft	26.0

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TABLE II. - SPIN-RECOVERY PARACHUTE TESTS ON A $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE

[Left spins; ailerons neutral; elevator up; normal loading; flaps neutral; recoveries attempted from established steady spins, rudder held with the spin]

Parachute diameter (ft)	Parachute drag coefficient	Vertical rate of descent (fps)	Turns for recovery	Towline length (ft)
Tail parachutes				
16.2	0.62	243	$1\frac{1}{4}, >4, \infty$	36
17.3	.56	243	$\frac{1}{2}, 1, >2, \infty$	36
19.5	.60	243	$\frac{1}{2}, \frac{1}{2}, \frac{3}{4}, \frac{3}{4}$	36
Wing-tip parachutes				
13.0	.58	243	$\frac{1}{2}, 1, 1\frac{1}{4}, 1\frac{1}{2}$	6
11.5	.61	243	$1, 1\frac{1}{4}, 1\frac{1}{2}$	11
8.7	.47	243	$1, 1\frac{1}{4}$	15
7.6	.59	243	$1\frac{1}{4}, 1\frac{1}{2}, 2$	18
6.1	.69	243	$2, 2\frac{1}{2}, >2\frac{1}{2}$	17

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TABLE III.- CONDITIONS OF THE $\frac{1}{26}$-SCALE MODELS OF THE DOUGLAS XTB2D-1

AIRPLANE INVESTIGATED IN THE LANGLEY FREE-SPINNING TUNNEL

[Flaps neutral, cockpit closed, landing-gear retracted, left erect spins except as noted]

No.	Type of spin	[a]Loading	Modification	Spin-recovery parachute	Figure	Data on Chart	Data on Table
1	Erect	1	None	None	1, 2	[b]1	
2	Inverted	1	None	None	---	2	
3	Erect	2	None	None	----	3	
4	Erect	3	None	None	----	4	
5	Erect	4	None	None	----	5	
6	Erect	1	Ventral fin 1	None	3		VII
7	Erect	1	Ventral fin 2	None	3	6	
8	Erect	1	Antispin fillets 1	None	4		VII
9	Erect	1	Antispin fillets 2	None	4		VII
10	Erect	1	Elevator chord extended	None	4		VII
11	Erect	1	Horizontal-tail span extension	None	4		VII
12	Erect	1	End plates	None	3	7	
13	Erect	1	Ventral fin 1 and antispin fillets 1	None	----		VII
14	Erect	1	Ventral fin 1 and antispin fillets 2	None	----		VII
15	Erect	1	Ventral fin 1 and antispin fillets 2 horizontal-tail span extension	None	----	8	
16	Erect	1	None	Tail	----		II
17	Erect	1	None	Wing tip	----		II

[a]1. Two torpedos, on inner racks.
2. Two torpedos, on inner racks, center of gravity 10 percent mean aerodynamic chord rearward of normal.
3. Four torpedos.
4. One torpedo on inner rack.

[b]Left and right spin data presented.

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TABLE IV.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR VARIOUS LOADING

CONDITIONS OF THE DOUGLAS XTB2D-1 AIRPLANE

No.	Loading	Weight (lb)	μ sea level	μ 20,000 feet	Center-of-gravity location		Moments of inertia about center of gravity			Inertia parameters		
					$x/\bar{c}$	$z/\bar{c}$	I_X (slug-feet^2)	I_Y (slug-feet^2)	I_Z (slug-feet^2)	$\frac{I_X - I_Y}{mb^2} \times 10^4$	$\frac{I_Y - I_Z}{mb^2} \times 10^4$	$\frac{I_Z - I_X}{mb^2} \times 10^4$
1	Normal loading	26,343	8.06	15.12	0.253	0.077	50,666	53,360	97,923	-7	-111	118
2	Two 1000 pound bombs	24,101	7.37	13.83	.271	.047	49,297	50,830	95,235	-4	-121	125
3	Four 1000 pound bombs	26,248	8.03	15.07	.259	.073	52,805	51,766	98,608	3	-117	114
4	Normal scout	23,040	7.05	13.23	.293	.019	48,680	49,963	94,877	-4	-128	132
5	Ferry airplane	29,465	9.01	16.91	.280	.066	78,578	65,608	136,113	31	-167	136
6	Overload bomber four 2000 pound bombs	33,510	10.25	19.24	.261	.104	83,659	58,594	128,938	64	-158	94
7	Overload torpedo four 2150 pound torpedos	34,069	10.42	19.56	.252	.111	80,363	56,723	129,110	48	-147	99
8	Asymmetric loading	24,111	7.37	13.84	.267	.049	49,471	51,631	95,986	-6	-120	126
9	Extreme nose heavy	24,003	7.34	13.78	.217	.096	54,211	51,999	98,370	6	-126	120
10	Extreme tail heavy	25,141	7.69	14.43	.306	.018	71,426	50,007	117,658	57	-180	123

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TABLE V.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADING CONDITIONS TESTED ON THE $\frac{1}{26}$-SCALE MODELS OF THE DOUGLAS XTB2D-1 AIRPLANE

[Model values converted to corresponding full-scale values, moments of inertia given about center of gravity]

No.	Loading	Weight (lb)	μ sea level	μ 20,000 feet	Center-of-gravity location		Moments of inertia about center of gravity			Inertia parameters		
					$x/\bar{c}$	$z/\bar{c}$	I_X (slug-feet^2)	I_Y (slug-feet^2)	I_Z (slug-feet^2)	$\frac{I_X - I_Y}{mb^2} \times 10^4$	$\frac{I_Y - I_Z}{mb^2} \times 10^4$	$\frac{I_Z - I_X}{mb^2} \times 10^4$
1	Normal loading	26,693	8.2	15.3	0.216	0.064	52, 472	51, 969	104,974	1	-130	129
2	Overload torpedo, four 2150 pound torpedos	31,971	9.8	18.4	.234	.112	70,307	49,774	121,727	42	-147	105
3	Asymmetric loading (exclusive of radar unit)	25,144	7.7	14.4	.255	.077	56,587	54,231	111,445	6	-149	143
4	Center of gravity 10 percent $\bar{c}$ aft of normal	27,521	8.4	15.8	.359	.019	55,665	54,792	109,349	2	-130	127

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TABLE VI.– TAIL DAMPING POWER FACTORS FOR THE VARIOUS TAIL CONFIGURATIONS TESTED ON THE $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE

No.	Tail configuration	TDR	URVC	TDPF
1	Original	0.0135	0.0146	197×10^{-6}
2	Antispin fillets 1	.0241	.0146	352
3	Antispin fillets 2	.0254	.0146	371
4	Elevator chord extension	.0135	.0146	197
5	Stabilizer and elevator span extension	.0135	.0146	197
6	Ventral fin 1	.0181	.0146	264
7	Ventral fin 2	.0210	.0243	510
8	Ventral 1 plus fillets 1	.0287	.0243	697
9	Ventral 1 plus fillets 2	.0300	.0243	729
10	Ventral 1, fillets 2, elevator and stabilizer span extension	.0300	.0243	729
11	Tip fins	.0335	.0243	814

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TABLE VII.- EFFECT OF VARIOUS MODIFICATIONS IN TAIL DESIGN ON SPIN AND RECOVERY CHARACTERISTICS

OF THE $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE

[Normal loading; recovery as indicated (recovery attempted from, and steady-spin data presented for rudder-full with spins); left erect spins]

	Antispin fillets 1			Antispin fillets 2							Elevator chord extension	Stabilizer and elevator Span extension
Ailerons	Neutral	With $\frac{1}{3}$	With Full	Against	Neutral		With $\frac{1}{3}$		With Full		Neutral	$\frac{1}{3}$ with
Elevator	Neutral	Up	Up	Up	Up	Neutral	$\frac{2}{3}$ up	Up	Up	Neutral	Up	$\frac{2}{3}$ up
α, deg	[a]25 42	43	47	28	[a]38 50	49	46	36	46	46	47	[a]29 50
ϕ, deg	2U 5D	3D	7D	5U	1U 6D	1U	0	5D	8C	3D	1D	3U 13D
Ω, rps	0.39	0.37	0.38	0.45	0.40	0.45	0.42	0.39	0.38	0.45	0.42	0.41
V, fps	282	254	233	342	275	226	243	286	247	229	243	282
Turns for recovery	[b]$>5\frac{1}{2}$, [b]>10 [c]$\frac{1}{2}$, [c]$\frac{3}{4}$	[d]$2\frac{1}{2}$ [d]3	[c]3	[c]$\frac{1}{4}$	[ce]$1\frac{1}{4}$ [c]2	[c]$3\frac{1}{2}$ [c]$4\frac{1}{2}$	[d]4 [d]4	[d]$1\frac{1}{4}$ [de]$1\frac{1}{2}$	[ce]$2\frac{1}{4}$ [c]$2\frac{1}{2}$	[c]$3\frac{3}{4}$ [c]$4\frac{1}{2}$	[f]>6 [g]$2\frac{1}{2}$ [g]$3\frac{1}{2}$	[d]2 [d]$2\frac{3}{4}$

	Ventral fin 1			Ventral fin 1 and antispin fillets 1	Ventral fin 1 and antispin fillets 2
Ailerons	Neutral	$\frac{1}{3}$ with		$\frac{1}{3}$ with	$\frac{1}{3}$ with
Elevator	Up	$\frac{2}{3}$ up	Up	$\frac{2}{3}$ up	$\frac{2}{3}$ up
α, deg	[a]28 43	[a]39 54	[a]38 47	[a]37 47	[a]27 45
ϕ, deg	4D 3U	0 2D	0 4D	0 5D	1U 8D
Ω, rps	0.40	0.41	0.39	0.41	0.42
V, fps	257	250	246	253	261
Turns for recovery	[c]$1\frac{1}{4}$ [c]2	[d]$2\frac{1}{4}$ [d]3 [h]$1\frac{1}{4}$ [h]2	[d]1 [d]$2\frac{1}{4}$	[di]1 [dj]$3\frac{1}{2}$	[di]1 [dj]$2\frac{1}{2}$

[a]Oscillatory spin, range of values given.
[b]Recovery by rudder reversal.
[c]Recovery by simultaneous full reversal of rudder and movement of the elevator to full down.
[d]Recovery by simultaneous reversal of rudder to 2/3 against and elevator to 1/3 down.
[e]Visual estimate.
[f]Recovery by simultaneous reversal of rudder from full with to full against and elevator from full up to 1/3 down.
[g]Recovery by simultaneous reversal of rudder from full with to full against and elevator from full up to full down.
[h]Recovery attempted by simultaneous reversal of rudder from full with to 2/3 against and elevator from 2/3 up to 2/3 down.
[i]Recovery attempted from steep part of oscillation.
[j]Recovery attempted from flat part of oscillation.

Model values converted to corresponding full-scale values.

U inner wing up
D inner wing down

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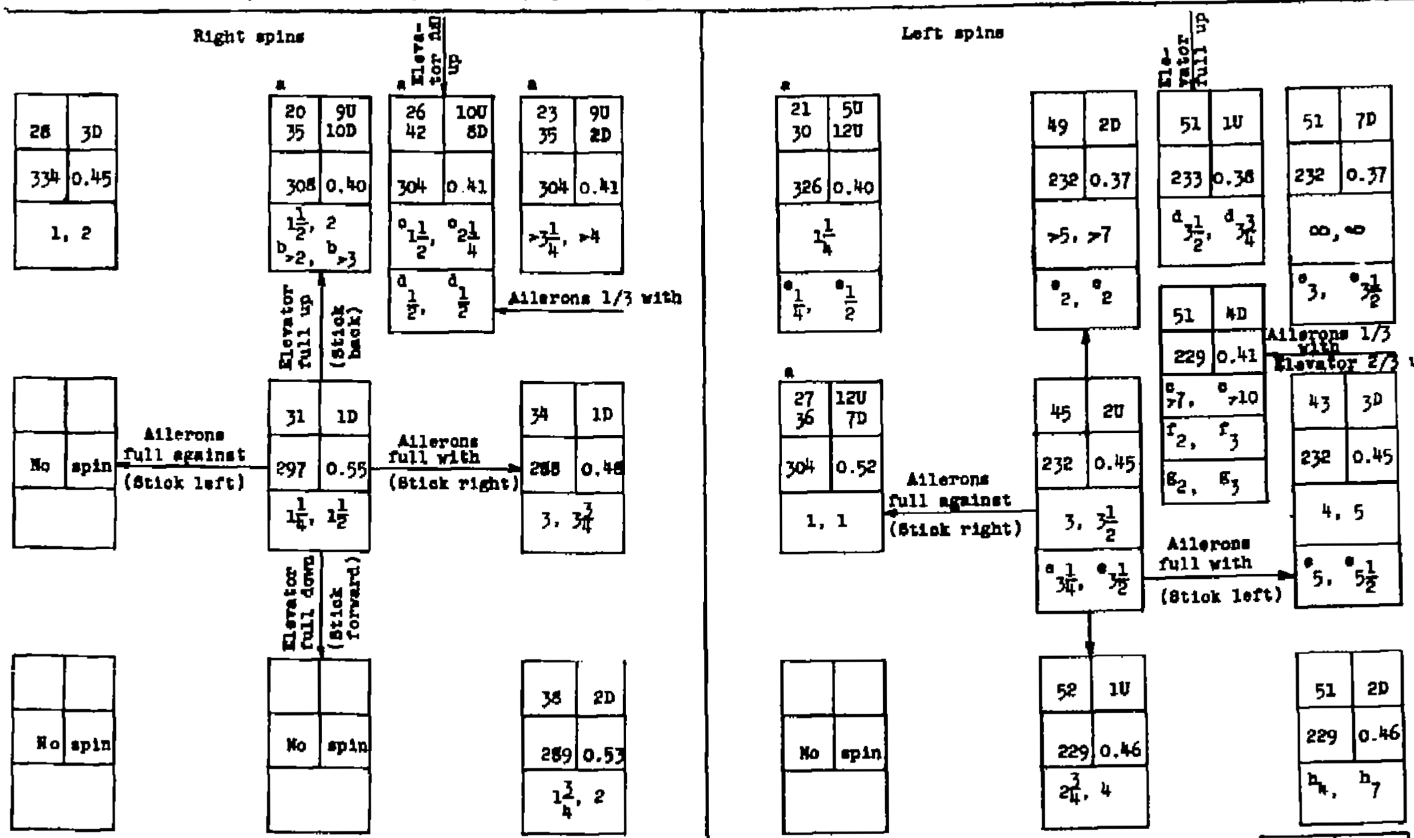
CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE IN THE NORMAL LOADING

[Loading point 1 on table V and figure 6; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); erect spins]



[a]Oscillatory spin, range of values given.
[b]Model on verge of recovery.
[c]Recovery attempted by reversing rudder from full with to 2/3 against the spin.
[d]Recovery attempted by simultaneously reversing rudder from full with to 2/3 against the spin and the elevator from full with to 1/3 down.
[e]Recovery attempted by simultaneous full reversal of rudder and movement of the elevator to full down.
[f]Recovery attempted by simultaneously reversing the rudder from full with to 2/3 against the spin and the elevator from 2/3 up to 1/3 down.
[g]Recovery attempted by simultaneously reversing the rudder from full with to 2/3 against the spin and the elevator from 2/3 up to 2/3 down.
[h]After recovery, model goes into inverted spin.

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Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

CHART 2.- INVERTED SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE IN THE NORMAL LOADING

[Loading point 1 on table V and figure 6; flaps neutral; cockpit closed; recovery attempted by rapid full rudder reversal (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); spins to pilot's left]

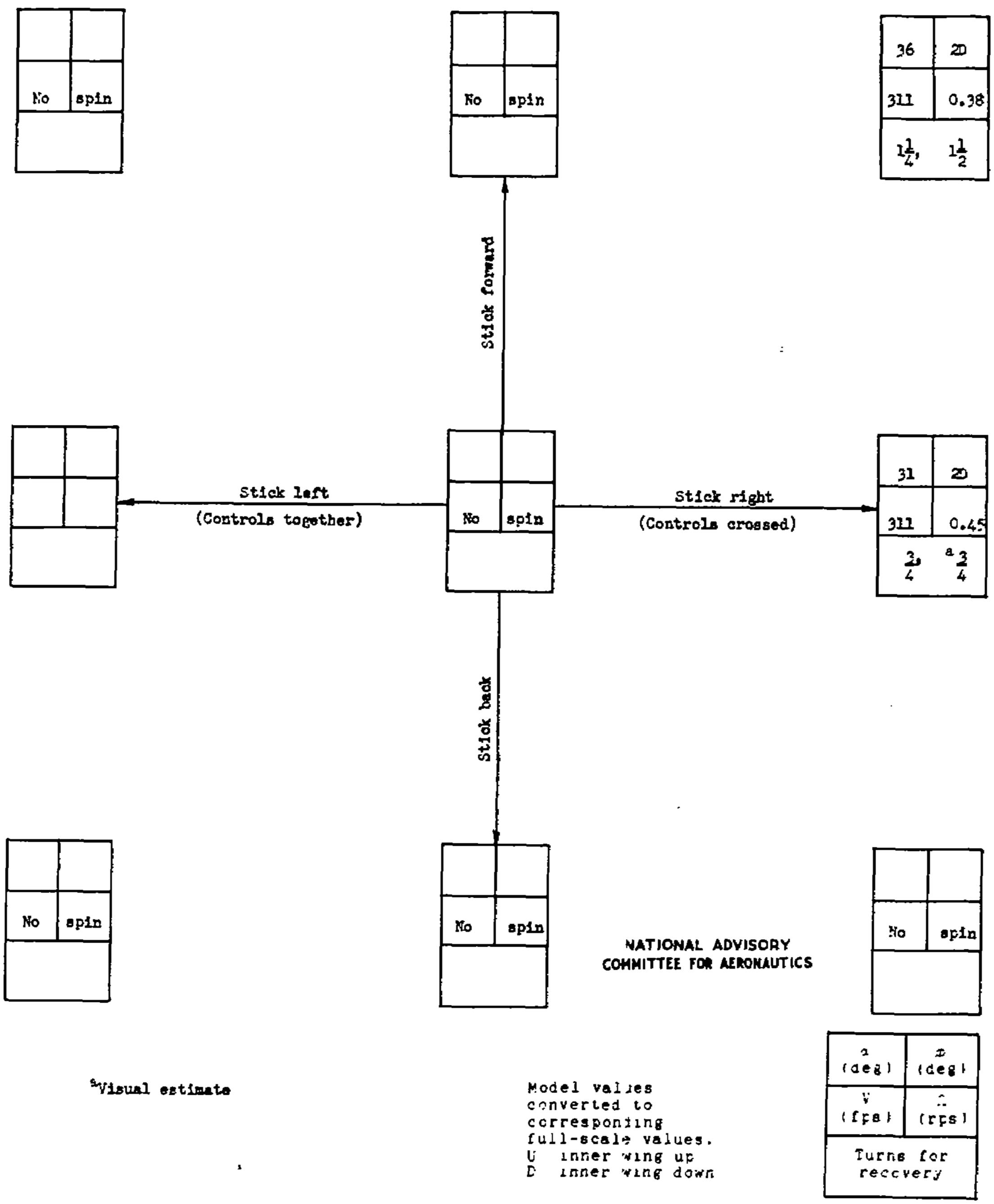
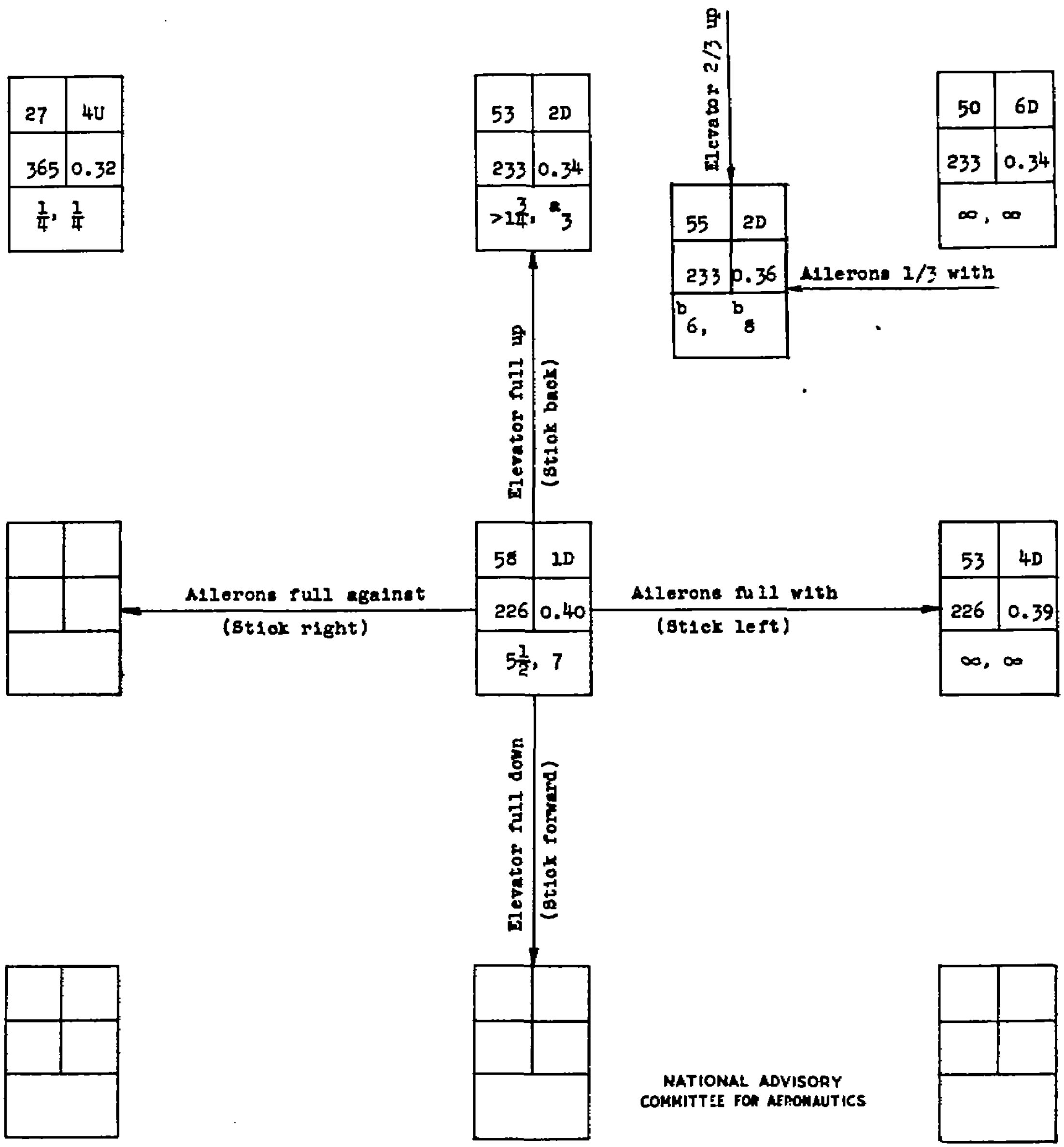


CHART 3.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE WITH THE CENTER OF GRAVITY MOVED REARWARD TEN PERCENT $\bar{c}$ FROM THE NORMAL LOCATION

[Loading point 4 on table V and figure 6; flaps neutral; cockpit closed; recovery attempted by simultaneous rapid full reversal of the rudder and elevator except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); left erect spins]



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[a]Visual observation.
[b]Recovery attempted by simultaneously reversing the rudder from full with to 2/3 against the spin and the elevator from 2/3 up to 1/3 down.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

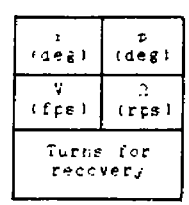
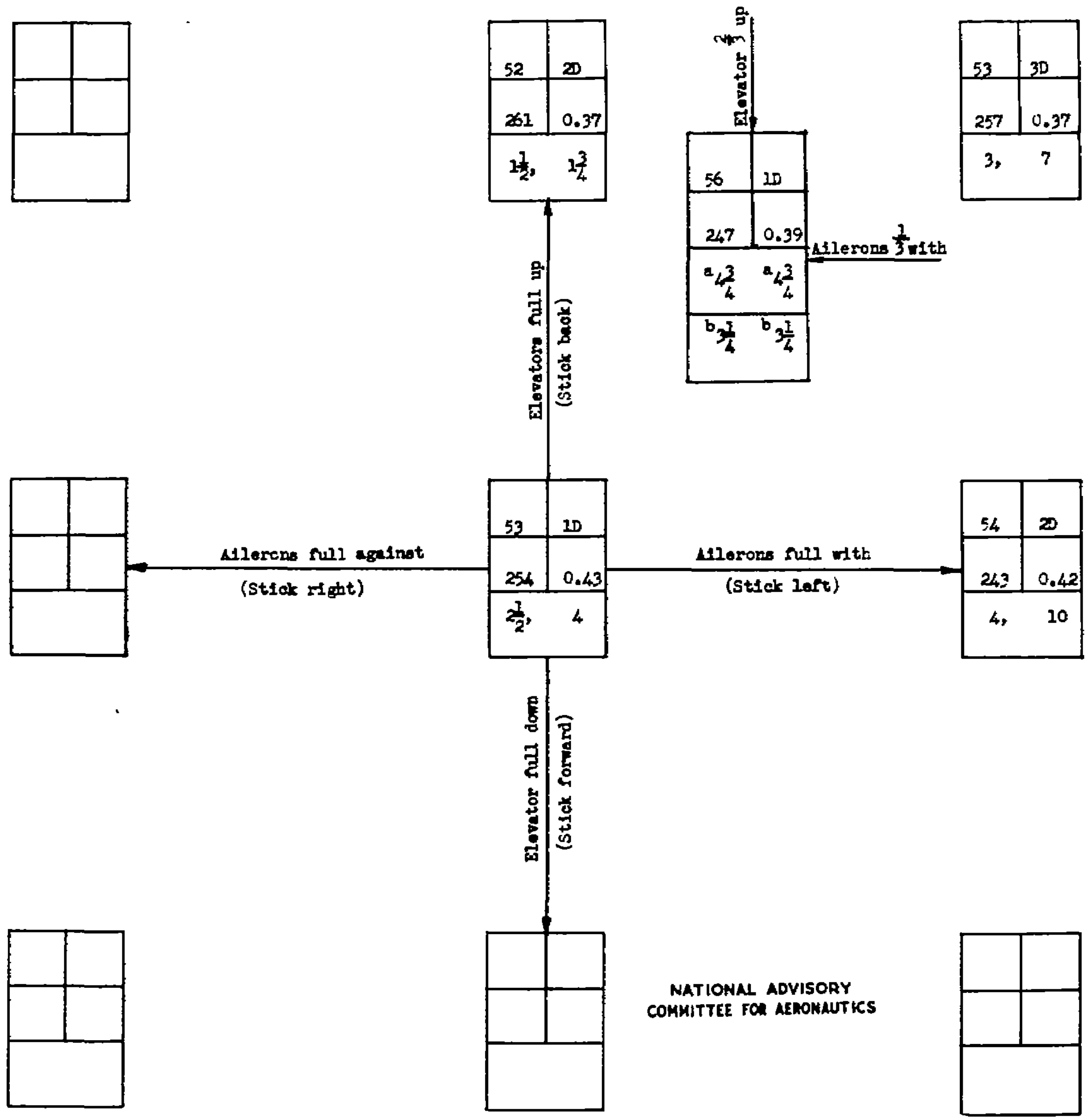


CHART 4.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE IN THE OVERLOAD TORPEDO CONDITION

[Loading point 2 on table V and figure 6; flaps neutral; cockpit closed; recovery attempted by simultaneous rapid full rudder and elevator reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); left erect spins]



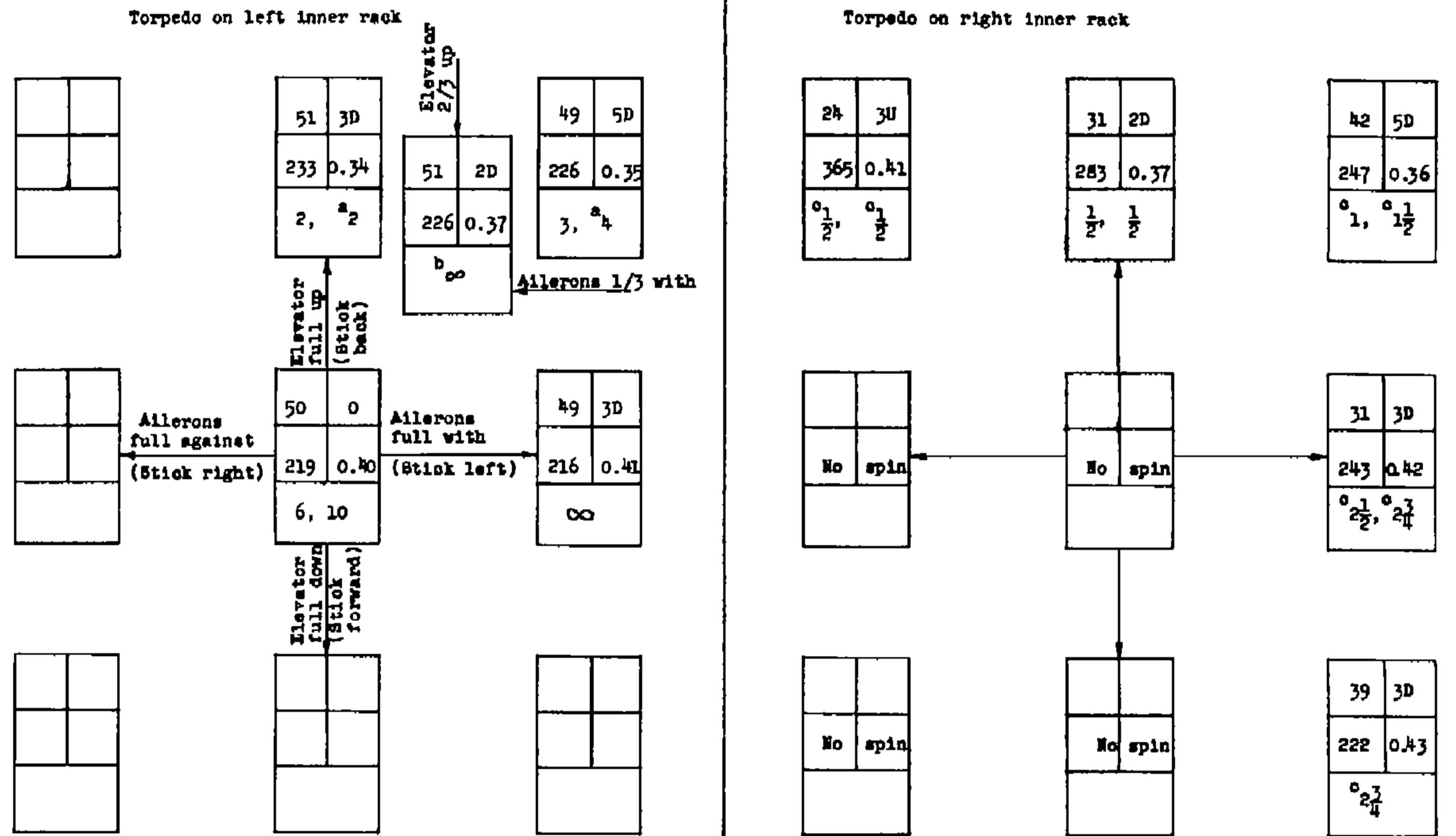
[a]Recovery attempted by simultaneously reversing rudder to 2/3 against the spin and the elevator to 1/3 down
[b]Recovery attempted by simultaneously reversing rudder to 2/3 against the spin and the elevator to full down

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

CHART 5.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{20}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE WHEN LOADED ASYMMETRICALLY

[Loading point 3 on table V and figure 6; flaps neutral; cockpit closed; recovery attempted by simultaneous rapid full reversal of the rudder and elevator except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); left erect spins]



[a]Visual estimate.
[b]Recovery attempted by simultaneously reversing the rudder from full with to 2/3 against the spin and the elevator from 2/3 up to 1/3 down.
[c]After recovery, model goes into inverted spin.

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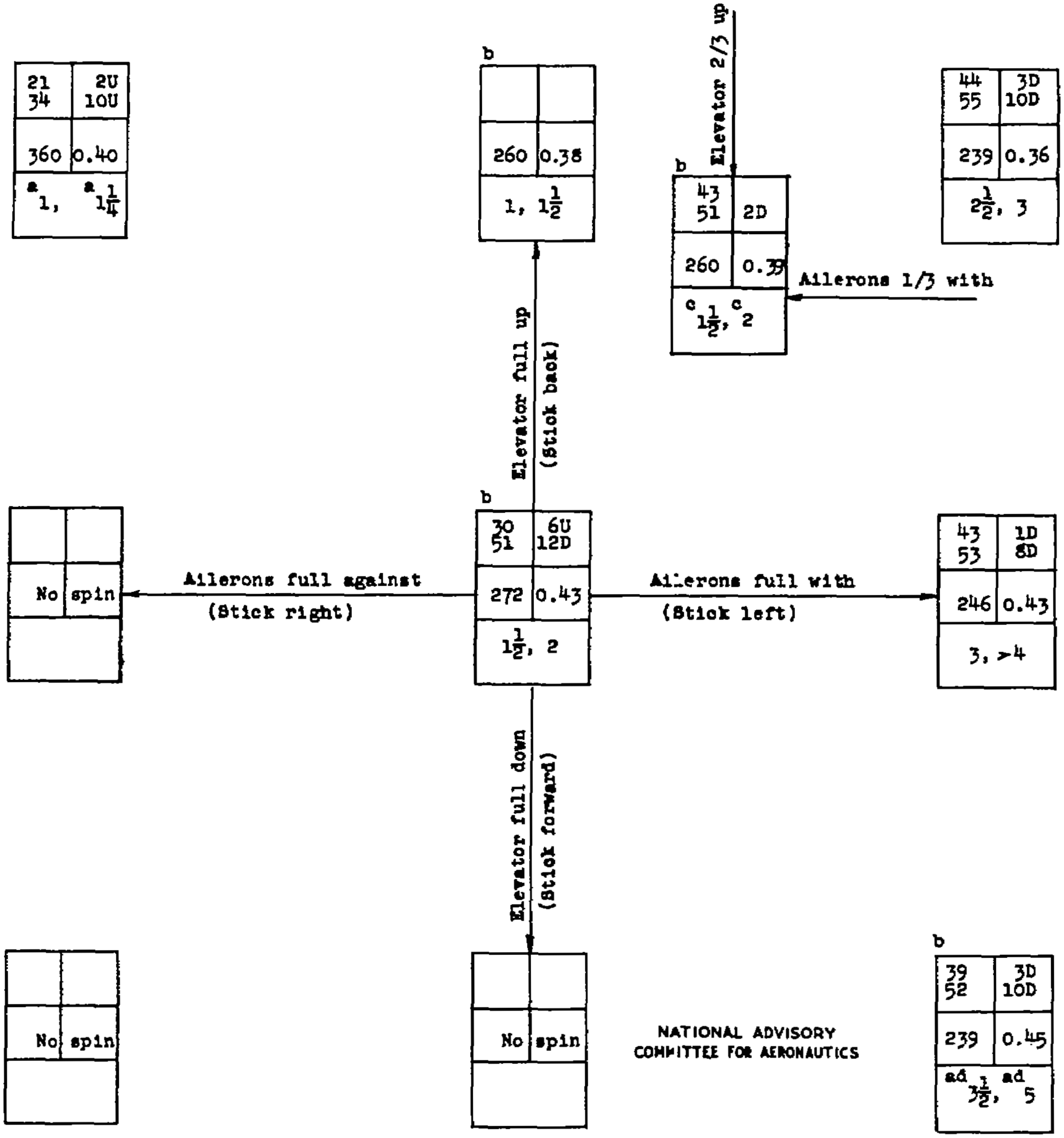
Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

CHART 6.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE WITH VENTRAL FIN 2 INSTALLED

[Loading point 1 on table V and figure 6; flaps neutral; cockpit closed; recovery attempted by simultaneous reversal of rudder and elevator except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); left erect spins]



[a]Recovery attempted by rudder reversal alone.
[b]Oscillatory spin, range of values given.
[c]Recovery attempted by simultaneous reversal of rudder to 2/3 against and elevator to 1/3 down.
[d]After recovery, model goes into inverted spin.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

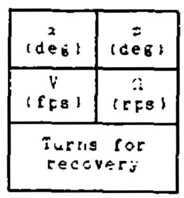
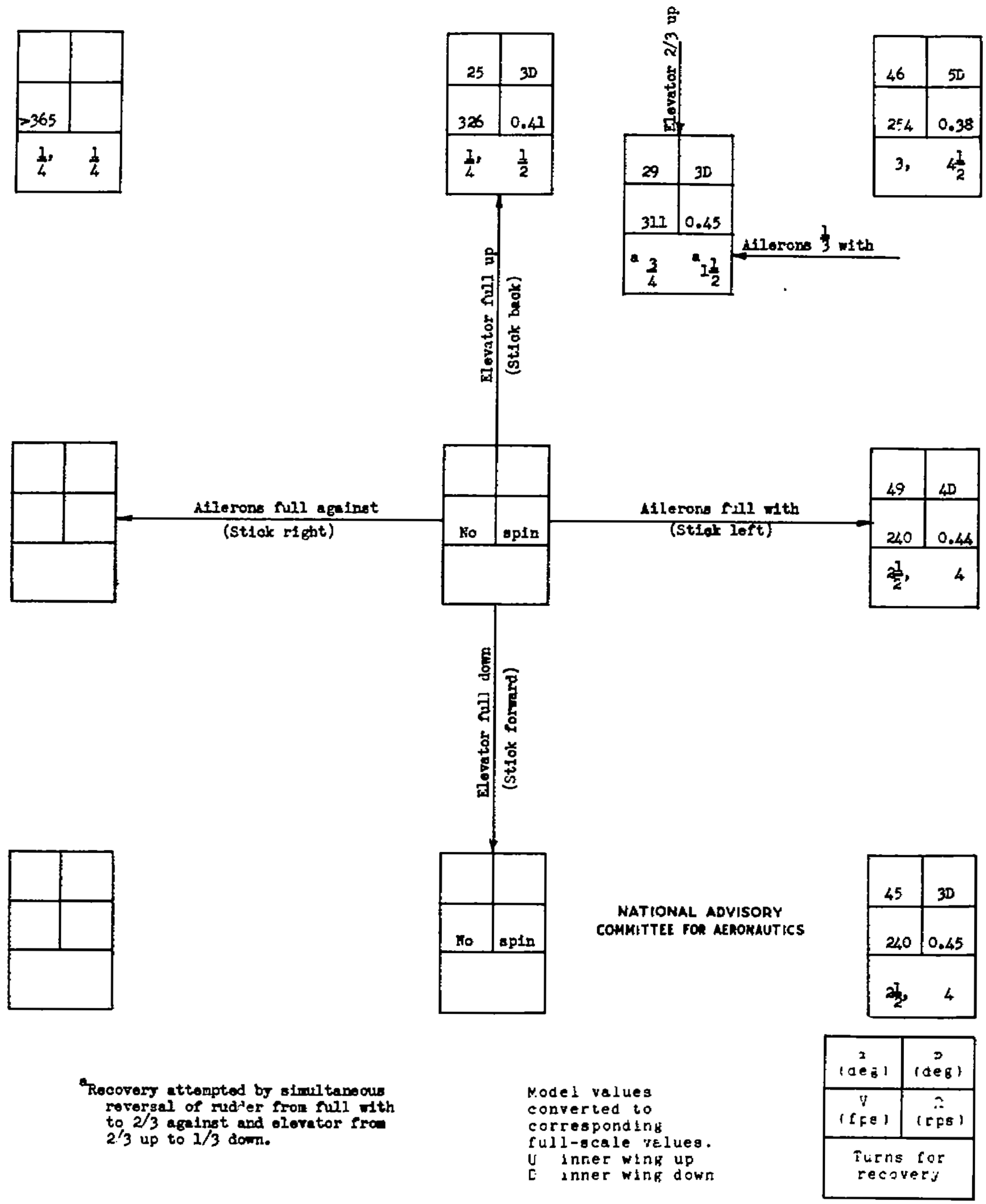


CHART 7.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{25}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE WITH TIP FINS INSTALLED ON THE HORIZONTAL TAIL

[Loading point 1 on table V and figure 6; flaps neutral; cockpit closed; recovery attempted by simultaneous rapid full reversal of the rudder and elevator except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); left erect spins]

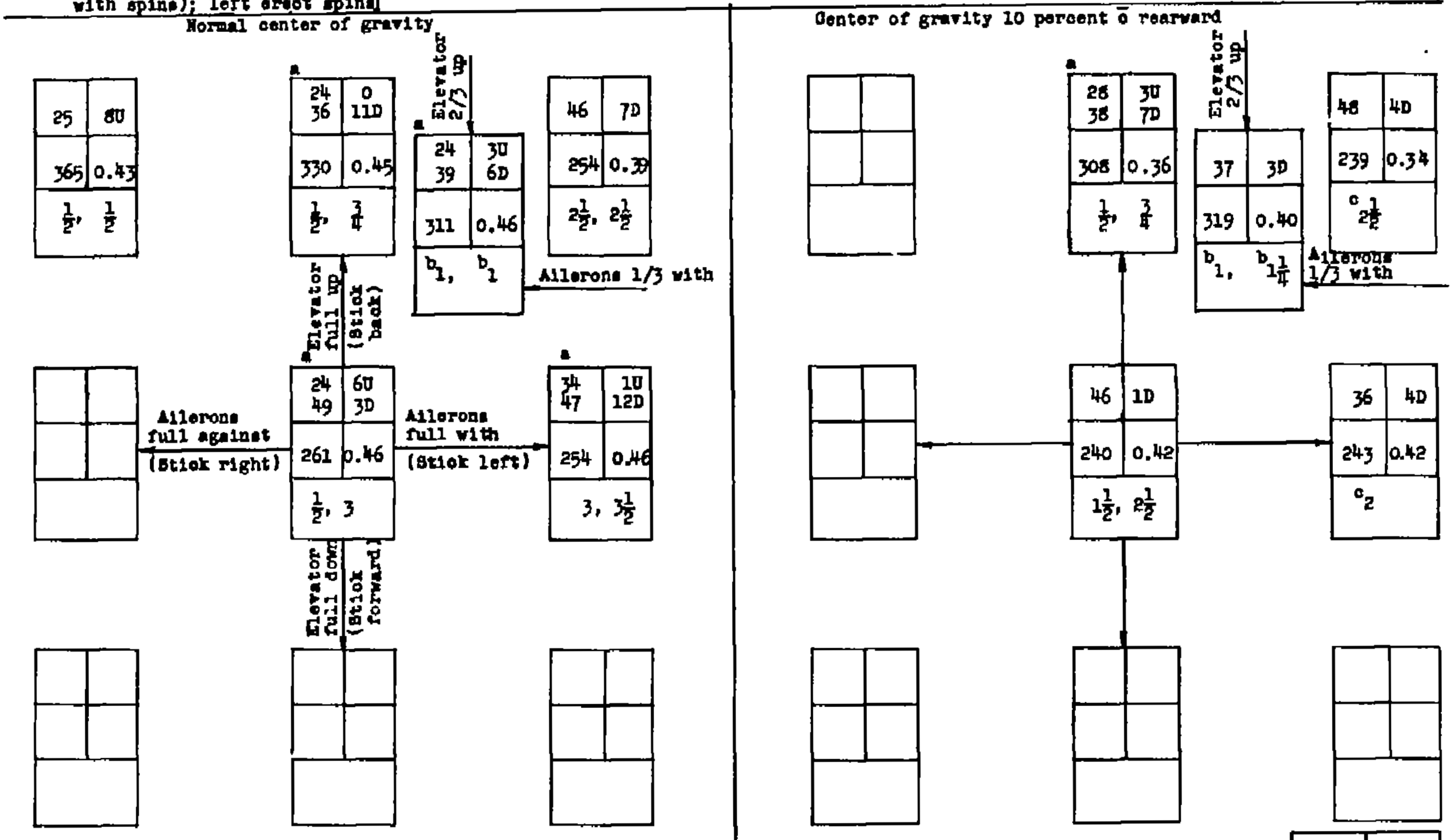


[a]Recovery attempted by simultaneous reversal of rudder from full with to 2/3 against and elevator from 2/3 up to 1/3 down.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

CHART 8.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{26}$-SCALE MODEL OF THE DOUGLAS XTB2D-1 AIRPLANE WITH VENTRAL FIN 1, ANTISPIN FILLETS 2, AND SPANWISE EXTENSION OF THE HORIZONTAL TAIL INSTALLED

[Loading points 1 and 4 on table V and figure 6; flaps neutral; cockpit closed; recovery attempted by simultaneous rapid full reversal of the rudder and elevator except as noted (recovery attempted from, and steady-spin data presented for, rudder-full-with spins); left erect spins]



[a]Oscillatory spin, range of values given.
[b]Recovery attempted by simultaneously reversing the rudder from full with to 2/3 against the spin and the elevator from 2/3 up to 1/3 down.
[c]After recovery, model went into an inverted spin.

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Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

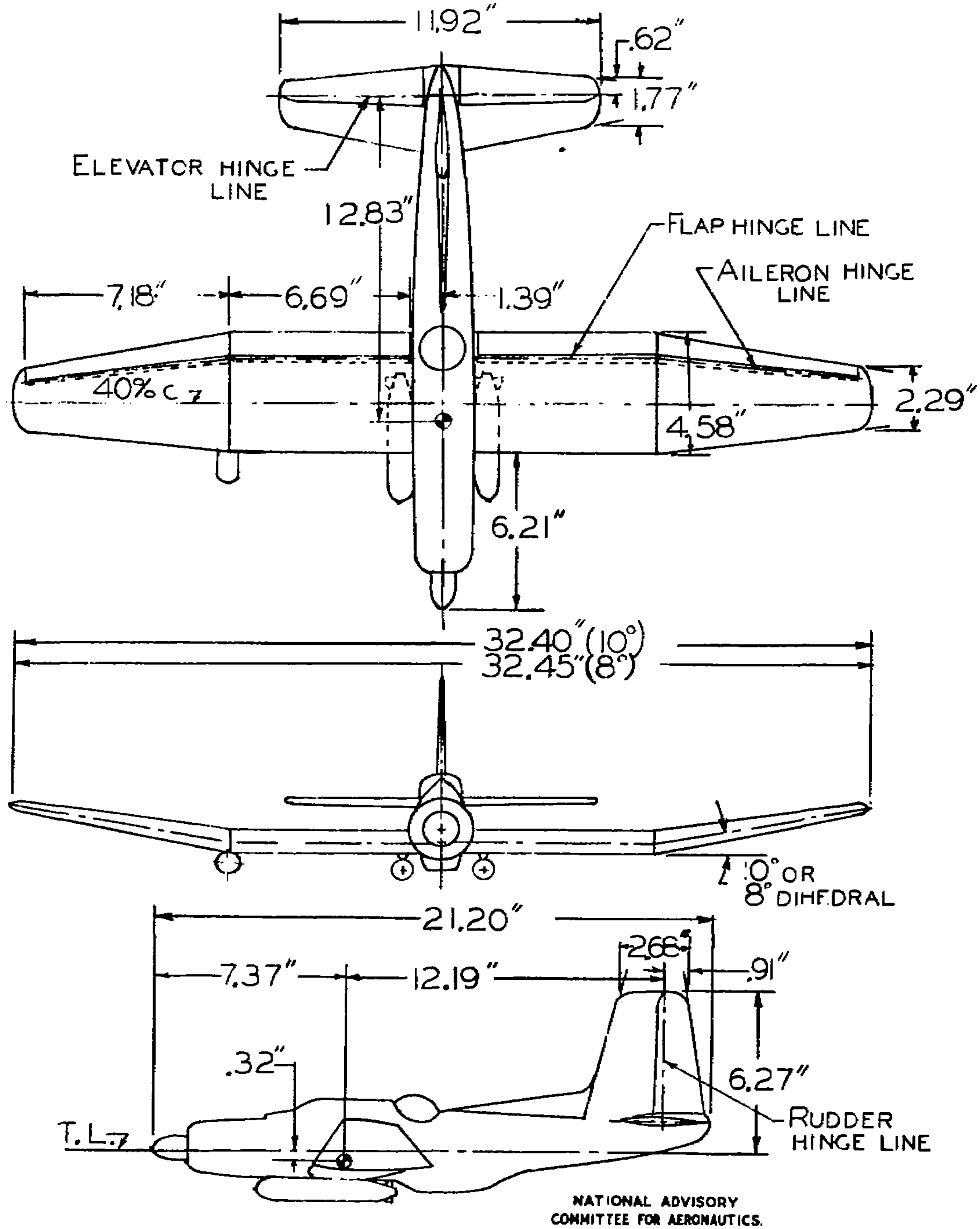

FIGURE 1. - THREE-VIEW DRAWING OF THE $\frac{1}{26}$-SCALE MODELS OF THE DOUGLAS XTB2D-1 AIRPLANE AS TESTED IN THE FREE-SPINNING TUNNEL. CENTER-OF-GRAVITY IS SHOWN FOR NORMAL LOADING. DIMENSIONS ARE MODEL VALUES.

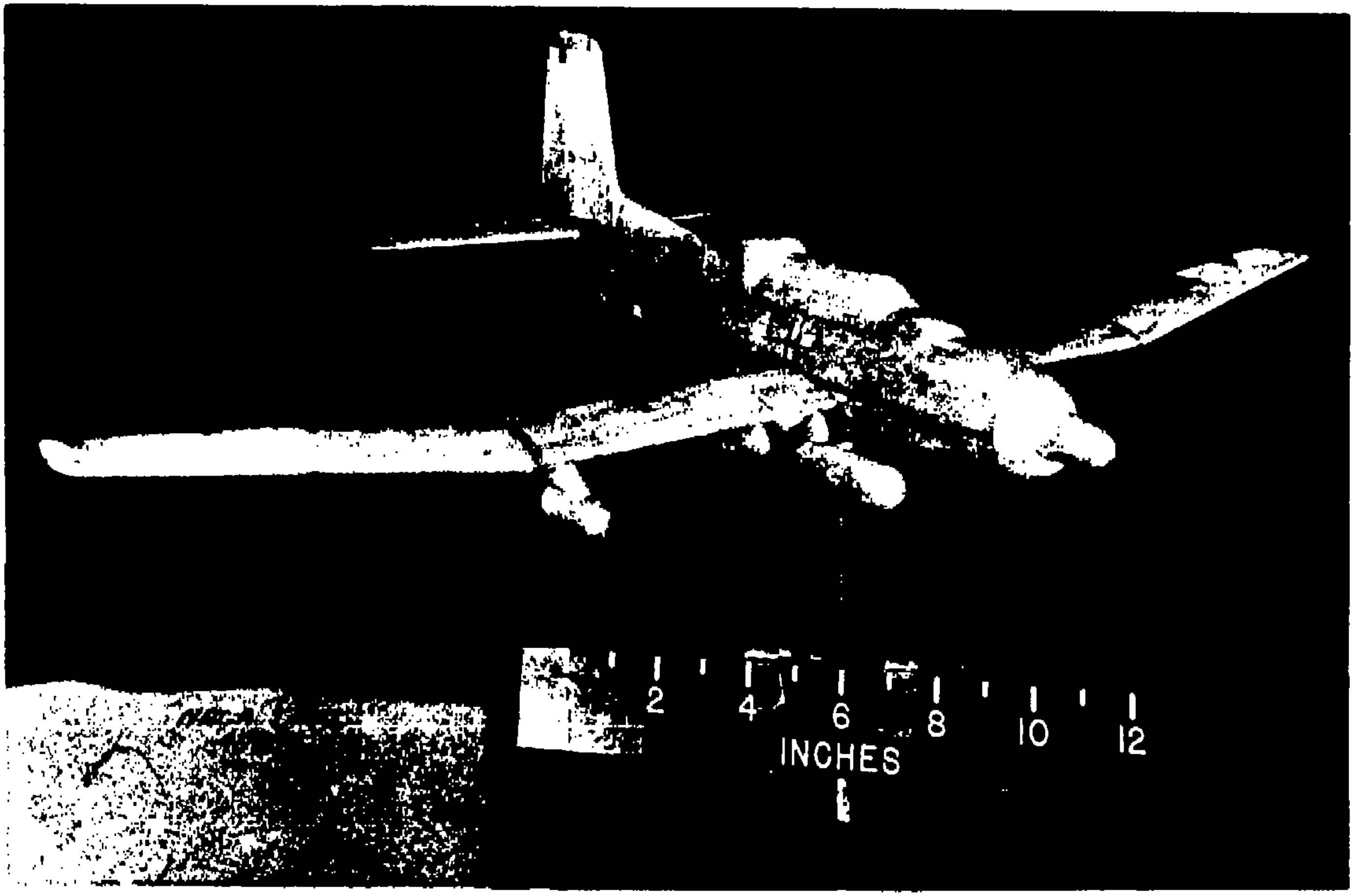

Figure 2.- Photograph of the $\frac{1}{26}$-scale model of the Douglas XTB2D-1 airplane in the normal loading.

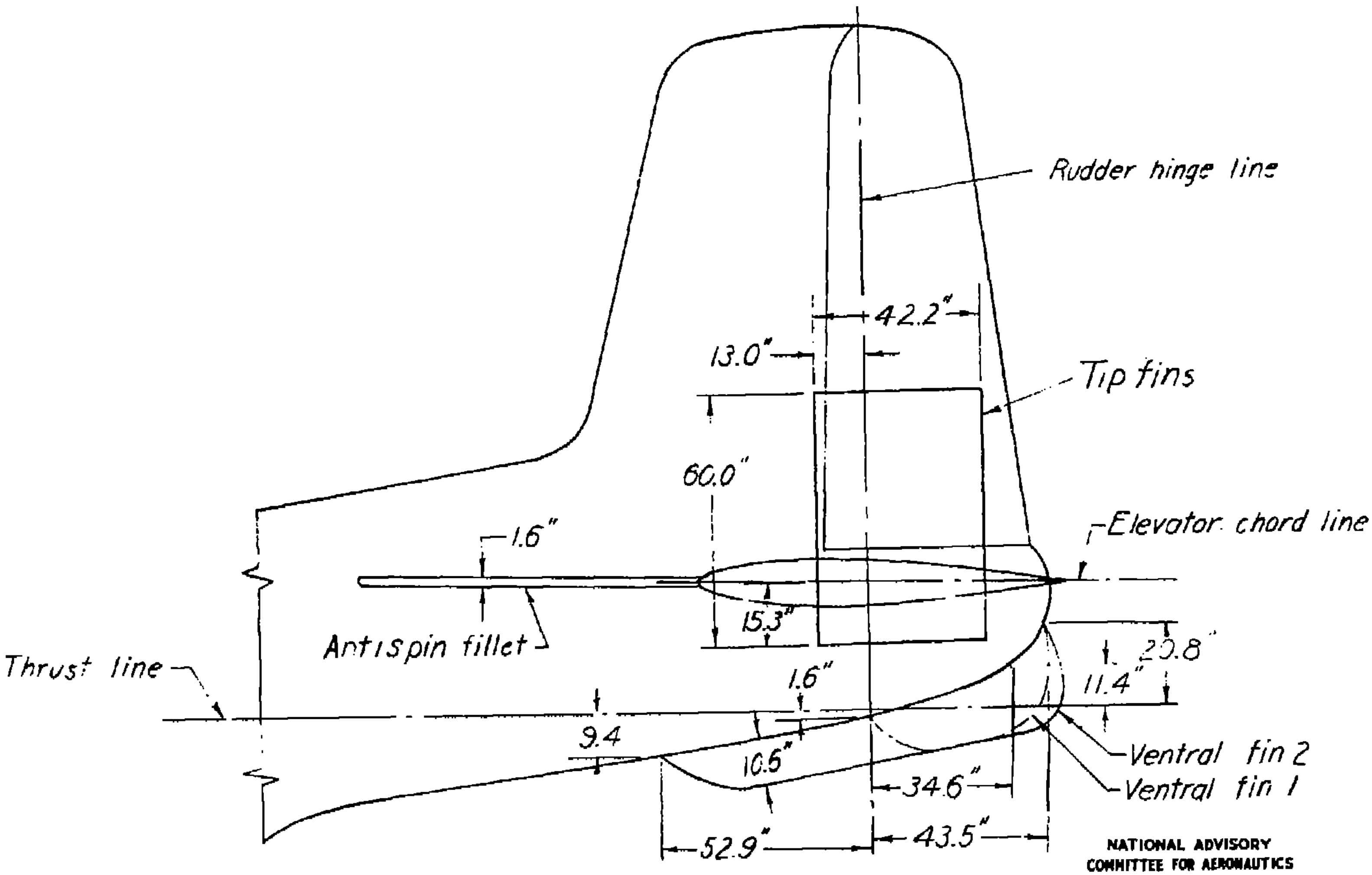

Figure 3.- Ventral fins, tip fins, and antispin fillets tested on a $\frac{1}{26}$-scale model of the Douglas XTB2D-1 airplane. Dimensions are full scale.

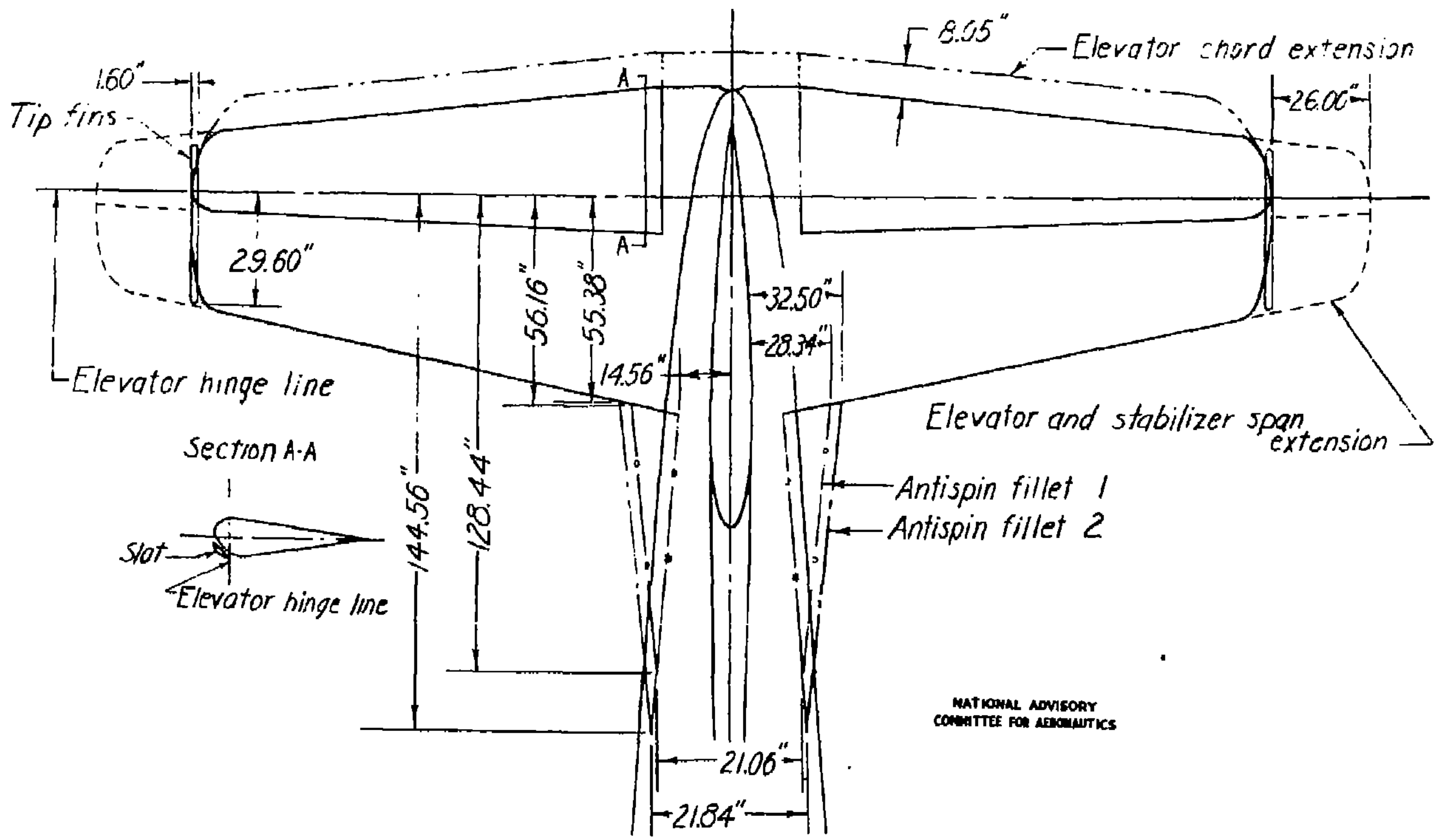

Figure 4 - Elevator chord extensions, stabilizer and elevator span extensions, antispin fillets, and tip fins tested on a $\frac{1}{26}$-scale model of the Douglas XTB2D-1 airplane. Dimensions are full scale.

Figure 5.- Photograph of the $\frac{1}{26}$-scale model of the Douglas XTB2D-1 airplane spinning in the Langley 20-foot spin tunnel.

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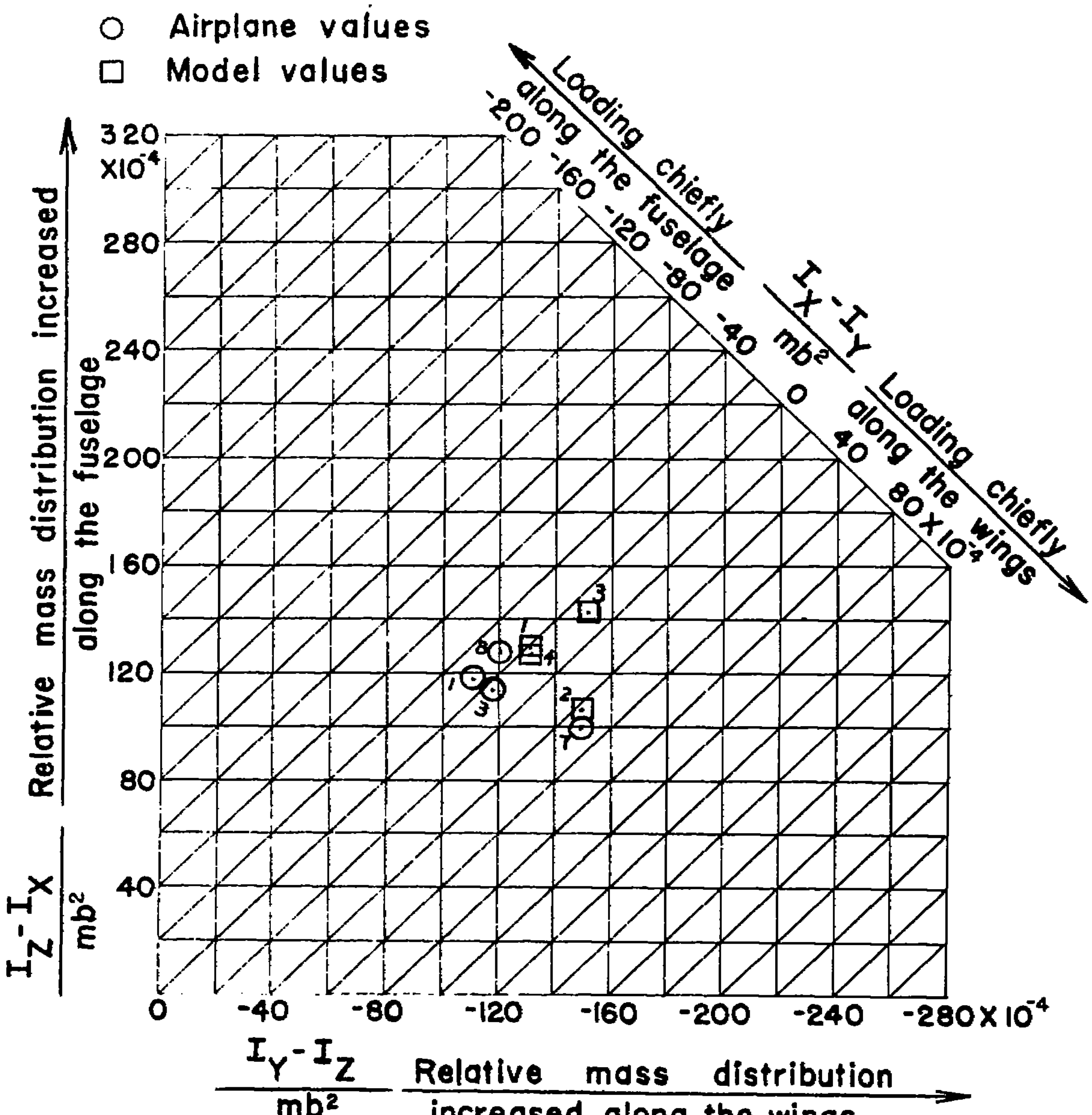

Figure 6.- Inertia parameters for loadings possible on the XTB2D-1 airplane and for the loadings tested on the 1/26-scale models. (Points are for loadings listed in tables IV and V.)